

1 EASY SET-UP, VEHICLE MOUNTED, IN-MOTION TRACKING, SATELLITE
2 ANTENNA
3

4 BACKGROUND OF THE INVENTION
5

6 1. Field of the Invention

7 The invention relates to vehicle mounted satellite antennae.
8 More particularly, the invention relates to a vehicle mounted
9 satellite antenna which is easy to install, has a low profile, and
10 which is operable while the vehicle is in motion.
11

12 2. State of the Art

13 It has long been known to mount a satellite antenna (dish)
14 atop a vehicle for purposes of communicating with a geostationary
15 or other type of satellite. The initial applications for mounting
16 a satellite dish on a vehicle were military communication and
17 remote television news broadcasting. Consequently, the first
18 methods of mounting a satellite dish included a telescoping mast
19 which was hingedly coupled to the vehicle. When the vehicle was
20 in motion, the mast would be retracted and folded with the
21 satellite dish lying end up on the roof or a side wall of the
22 vehicle. The dish would be deployed only when the vehicle was
23 stationary. Such a deployable vehicle mounted satellite dish is
24 disclosed in U.S. Patent Number 5,961,092 to Coffield. Until

1 recently, no vehicle mounted satellite antennae were operable
2 while the vehicle was in motion. The relatively large size of a
3 conventional satellite dish antenna presents significant wind
4 resistance if deployed on a vehicle in motion. This wind
5 resistance adversely affects the operation of the vehicle and
6 subjects the satellite dish to potential wind damage. Moreover,
7 satellite dishes must be accurately aimed at a satellite within a
8 relatively narrow aperture or "look window". In order to operate
9 a satellite dish mounted on a vehicle in motion, it would be
10 necessary to constantly re-aim the dish in order to maintain
11 communication with the satellite.

12
13 Recently, satellite antennae have been developed which may be
14 deployed on a vehicle and operated while the vehicle is in motion.
15 Such antennae are disclosed in U.S. Patent Number 5,398,035 to
16 Densmore et al., U.S. Patent Number 5,982,333 to Stillinger, and
17 U.S. Patent Number 6,049,306 to Amarillas. These antenna systems
18 generally include a satellite antenna of reduced size and a
19 solenoid system for aiming the antenna. The solenoid system is
20 coupled to a feedback system and/or vehicle motion detectors in
21 order to automatically re-aim the antenna as the vehicle is in
22 motion. In order to reduce aerodynamic drag and protect the
23 antenna from wind damage, an aerodynamic radome is often used to
24 cover the antenna.

1 Vehicle mounted satellite antennae which are operable while
2 the vehicle is in motion, can provide one-way or two-way satellite
3 communications. Some applications for such antennae include
4 satellite television reception, telephony in remote locations
5 where cellular telephone service is unavailable, and broadband
6 data communications. The application of television reception may
7 be advantageously applied in common carrier transportation such as
8 long distance buses, in recreational vehicles including boats, and
9 in the rear seats of family mini-vans. The application of remote
10 telephony may be applied in the same situations as well as in
11 various other governmental and commercial settings. The
12 application of broadband data communication may also be applied in
13 many personal, commercial, and governmental settings.

14
15 Broadband satellite communication, such as television
16 reception or broadband data communication, requires a high gain
17 antenna with high cross-polarization isolation and low signal
18 sidelobes. Satellite antenna gain is proportional to the aperture
19 area of the reflector. Stationary satellite antennae typically
20 utilize a circular parabolic reflector. Satellite antennae
21 designed for use on a moving vehicle have a low profile. In order
22 to maintain gain, these low profile antenna are short but wide so
23 that the overall aperture area is kept high. However, this design
24 strategy only works to a point. When the width to height ratio

1 exceeds a certain value such as 2, the efficiency of the antenna
2 is adversely affected. The presently available vehicle mountable
3 satellite antenna for commercial and personal use are no shorter
4 than approximately fifteen inches in height.
5

6 In addition to the issue of providing low profile tracking
7 antennae, the process of installing a satellite antenna on a
8 vehicle is not trivial. Holes must be drilled through the roof
9 (or body panel) of the vehicle; coaxial cable must be routed from
10 the antenna to a receiver or transceiver; and power cables must be
11 routed to the antenna's tracking system. The installation process
12 is therefore time consuming and costly.
13

14 SUMMARY OF THE INVENTION 15

16 It is therefore an object of the invention to provide a
17 vehicle mountable satellite antenna.
18

19 It is also an object of the invention to provide a vehicle
20 mounted satellite antenna which is operable while the vehicle is
21 in motion.
22

23 It is another object of the invention to provide a vehicle
24 mounted satellite antenna which has a low profile.

1 It is also an object of the invention to provide a vehicle
2 mounted satellite antenna which has high gain.

3
4 It is another object of the invention to provide a vehicle
5 mounted satellite antenna which has high efficiency.

6
7 It is still another object of the invention to provide a
8 vehicle mountable satellite antenna which is easy to install.

9
10 In accord with these objects which will be discussed in
11 detail below, the satellite antenna of the present invention
12 includes two low profile paraboloid linear reflector antenna
13 assemblies mounted on a rotatable platform which is rotatably
14 coupled to a base plate. Each antenna assembly is provided with
15 two sub-reflectors with a plastic matching element between them.
16 The two antenna assemblies are mounted parallel to each other and
17 are pivotable relative to the rotatable platform. A first servo
18 motor is coupled to the rotatable platform for azimuth tracking.
19 A second servo motor is coupled by a rigid arm to both antenna
20 assemblies for elevation tracking. The two antennae assemblies
21 are each provided with a line feed for receiving a polarized
22 satellite signal. A number of slot antenna probes are located in
23 the back of each antenna assembly. The signal is coupled from the
24 slot antenna into a microwave PCB or waveguide in the back of each

1 antenna. The antenna probes are attached to a microwave circuit
2 board, where two orthogonal linearly polarized signals are
3 extracted. The two linearly polarized signals are fed into a 90°
4 hybrid and two circularly polarized signals are extracted. The
5 signals of the same circular polarization from the same antenna
6 assembly are amplified and combined into a single signal in a beam
7 forming network (BFN) circuit on the microwave PCB.

8
9 In order to correct for time delay difference in the signals
10 received by the two antenna assemblies, a phase shifter is
11 employed to correct for the phase shift for the signal received
12 from one antenna before it is combined with the other antenna. A
13 unique feature of this antenna design is that only one phase
14 shifter is required, thereby achieving a very low cost design as
15 compared to the conventional phased array antenna implementation
16 which typically requires a large number of phase shifters.

17
18 According to an alternate embodiment, the backside of each
19 antenna dish is provided with a rectangular wave guide structure
20 with a step tooth polarizer stud in the middle of the wave guide.
21 The polarizer stud within the rectangular wave guide converts the
22 signal from linear polarization to circular polarization. Each
23 antenna contains two rows of multiple antenna feeds distributed
24 over the entire length of the antenna. The upper row of antenna

1 feeds extracts a (left or right) circularly polarized signal and
2 the lower row of antenna feeds extracts a (right or left)
3 circularly polarized signal. Each row of antenna feeds is
4 connected via a circuit board or wave guide to a beam forming
5 network (BFN) where signals are amplified and combined into a
6 single signal. The output of one of the BFNs is connected to the
7 input of a phase shifter via a flexible coaxial cable. The output
8 of the other BFN is connected to either an attenuator or an
9 amplifier (depending on whether the phase shifter amplifies or
10 attenuates the other signal) and then to one input port of a two-
11 to-one combiner via a flexible coaxial cable. The output of the
12 phase shifter is connected to the other input port of the
13 combiner. The amplifier or attenuator is used to amplify or
14 attenuate the signal by the same amount as the gain or loss of the
15 phase shifter so that the power of the signals from both BFN's are
16 equal before they are combined.

17
18 Dividing the antenna physical aperture into two or more
19 paraboloid linear dishes reduces the overall height of the antenna
20 array by half. Providing each cylindrical dish with multiple
21 feeds instead of single feed maintains the overall antenna
22 efficiency.

23

1 The combined signal from the two paraboloid linear antennae
2 is routed through a rotary joint, which routes the received signal
3 to circuits located under the rotatable platform but above the
4 base plate. According to the preferred embodiment of the
5 invention, the circuits between the rotatable platform and the
6 base plate include a re-transmitter for transmitting received
7 satellite signals (at a longer wavelength) to a first receiver
8 inside the vehicle. A second receiver is also preferably provided
9 on the base plate. According to one embodiment of the invention,
10 the second receiver is used to receive channel selection signals
11 and other control signals transmitted by a transmitter inside the
12 vehicle. According to another embodiment, a transceiver is used
13 at the base plate to provide two-way wireless communication with
14 equipment, such as telephones and computers, through another
15 transceiver inside the vehicle.

16
17 The use of the re-transmitter and second receiver between the
18 rotatable platform and the base plate eliminates the need for
19 signal wiring between the antennae assembly and the interior of
20 the vehicle. According to a preferred embodiment of the
21 invention, an independent power supply is also provided between
22 the rotatable platform and the base plate to eliminate the need
23 for power wiring between the antennae assembly and the interior of
24 the vehicle. According to one preferred embodiment, the

1 independent power supply includes a storage device such as a
2 battery or a coil and a charging device such as a wind powered
3 generator. A solar cell array may also be used as a charging
4 device.

5
6 According to other aspects of the invention, electronic
7 dithering systems are used to track a satellite quickly while a
8 vehicle is in motion. Methods are also provided for adjusting the
9 bias of motion sensors via the use of longitudinal and lateral
10 accelerometers. Methods are also provided for receiving either
11 circularly polarized or linearly polarized signals. According to
12 one embodiment of the invention, the "data port" of a conventional
13 satellite receiver settop box is used determine the appropriate
14 phase shift in the antennae array for a selected channel.

15
16 According to another aspect of the invention, the antenna
17 system is provided with a retractable radome. When the antenna is
18 not in use, the two cylindrical dishes are aimed straight up,
19 decreasing the overall height of the system, and the radome is
20 retracted.

21
22 Additional objects and advantages of the invention will
23 become apparent to those skilled in the art upon reference to the

1 detailed description taken in conjunction with the provided figures.

2
3 BRIEF DESCRIPTION OF THE DRAWINGS
4

5 Figure 1 is an exploded perspective view illustrating some of
6 the major components of the invention;
7

8 Figure 1a is a plan view of one embodiment of an azimuth
9 turntable drive;
10

11 Figure 1b is a plan view of an alternate embodiment of an
12 azimuth turntable drive;
13

14 Figure 2 is a schematic side elevation view illustrating the
15 relative placement of reflectors and beam forming network;
16

17 Figure 3 is a schematic view of a thirty-two element beam
18 forming network;
19

20 Figure 3a is an enlarged view of a portion of Figure 3
21 illustrating how four signals are combined before feeding the
22 combined signals to a low noise amplifier;
23

1 Figure 4 is a perspective view of an alternate embodiment of
2 an antenna assembly according to the invention;

3
4 Figure 5 is a schematic side elevation view of a portion of
5 the assembly of Figure 4;

6
7 Figure 6 illustrates an alternate embodiment of a beam
8 forming network utilized with the antenna embodiment of Figures 4
9 and 5;

10
11 Figure 7 is a simplified schematic diagram of a wireless
12 retransmission system according to the invention;

13
14 Figures 7a and 7b illustrate methods of the invention for
15 determining appropriate phase shift for a selected channel;

16
17 Figure 8 is a schematic side elevation view of mechanical
18 linkage coupling the two antennae for elevation tracking;

19
20 Figure 9 is a view similar to Figure 8 illustrating relative
21 location of the antennae to minimize blockage;

22
23 Figure 10 is a graph of array pattern side lobe effects;

1 Figure 11 is a simplified schematic diagram of a presently
2 preferred embodiment of the two tuners of Figure 5;

3
4 Figure 12 is a plan view of a radome with a wind powered
5 generator according to the invention;

6
7 Figure 13 is a partially cut away side elevation view of a
8 radome with a wind powered generator according to the invention;

9
10 Figure 14 is a schematic side elevation view illustrating the
11 antennae system of the invention mounted to the roof of a vehicle;

12
13 Figure 15 is a schematic side elevation view illustrating two
14 positions of the retractable radome of the invention; and

15
16 Figure 16 is a schematic side elevation view illustrating two
17 positions of the retractable radome of the invention with the
18 antennae aimed straight up.

19
20 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

21
22 Referring now to Figures 1 and 2, the satellite antenna 10 of
23 the present invention includes two low profile paraboloid linear
24 reflector antenna assemblies 12, 14 mounted on a rotatable

1 platform (turntable) 16 which is rotatably coupled to a base plate
2 18 via a rotary joint and slip ring 20. The rotary joint is an
3 off-the-shelf product which permits a high frequency signal to be
4 conducted through a rotary joint. The slip ring consists of a
5 number of circular traces on a circuit board and a corresponding
6 number of "brushes" which contact the circular traces. The slip
7 ring is used to conduct low frequency signals. The two antennae
8 are mounted parallel to each other and are pivotable relative to
9 the rotatable platform. A first servo motor (shown schematically
10 in Figure 7 as 114) is coupled to the rotatable platform for
11 azimuth tracking. A second servo motor 22 (Figure 1) is coupled
12 by a rigid arm 24 (also shown in more detail in Figure 8) to both
13 antenna assemblies for elevation tracking.

14
15 As shown in Figure 1a, the presently preferred construction
16 of the rotatable platform 16 contains a gear 16a which meshes on
17 its circumference with a worm gear 17 fixedly mounted on a shaft,
18 which is coupled through a gear box 19 to the rotary shaft of an
19 azimuth drive motor 114. A rotary optical encoder (not shown) is
20 coupled to the rotary shaft of the azimuth drive motor 114. The
21 azimuth drive motor is fixedly mounted on the stationary base
22 plate (18 in Figure 1), and hence when it is energized for
23 rotation in the forward or reverse direction, it turns the
24 rotatable platform clockwise or counter-clockwise as viewed from

1 the top, thus pointing the antennae to the left or right in the
2 azimuth direction. The optical encoder delivers pulses
3 corresponding to the amount of rotation in azimuth direction. The
4 number of pulses is counted which allows a microprocessor which
5 controls the azimuth movement of the rotatable platform to know
6 the exact amount of platform movement in the azimuth direction. A
7 magnet (not shown) mounted on the rotatable platform and a Hall
8 effect sensor (not shown) fixedly mounted to the stationary base
9 plate delivers a pulse to the microprocessor when the platform
10 reaches a "Home" position.

11
12 An alternative embodiment is shown in Figure 1b where a spur
13 gear 17' engages teeth 16a' on the perimeter of the turntable 16.
14 The worm gear arrangement of Figure 1a is preferred because it
15 will inherently lock the turntable in position when the motor is
16 stopped. If the spur gear embodiment of Figure 1b is used, it is
17 desirable to electrically shunt the motor when it is not running
18 to thereby lock the turntable in position.

19
20 As shown in Figure 1, the antennae 12, 14 are mechanically
21 linked to a rotary shaft 22a. The rotary shaft 22a fixedly
22 carries a gear (not shown) which meshes with a gear (not shown)
23 fixedly mounted on the output shaft (not shown) of a gear box (not
24 shown). The gear box includes an input shaft (not shown) which is

1 engaged by the rotary shaft (not shown) of an elevation motor
2 drive 22. A rotary encoder (not shown) is coupled to the rotary
3 shaft of the motor. The elevation drive motor 22 is fixedly
4 mounted on a support bracket on the rotatable platform 16. When
5 the motor 22 is energized for rotation, it rotates the two
6 antennae integrally in an upward or downward direction to point
7 the antennae to the desired elevation angle. The rotary encoder
8 delivers pulses corresponding to the amount of rotation in
9 elevation direction. The number of pulses is counted which allows
10 the microprocessor (112 in Figure 7) which controls the elevation
11 movement of the rotatable platform to know the exact amount of
12 platform movement in the elevation direction. A magnet (not
13 shown) mounted on the antenna and a Hall effect sensor (not shown)
14 fixedly mounted to the rotatable platform delivers a pulse to the
15 microprocessor when the antennae reach a "Home" position.
16 Alternatively, a mechanical gimbal stopper and reed switch can be
17 used to detect if the antenna reaches the gimbal limit.

18
19 As seen best in Figure 2, according to a first embodiment,
20 each antenna assembly 12, 14 includes a bifurcated main reflector
21 26a, 26b which focuses onto a pair of subreflectors 28a, 28b which
22 are mounted on a plastic matching and support structure 30. The
23 subreflectors focus onto a slot antenna 32 which is coupled to a
24 beam forming network 34. In addition, signals from a satellite

1 are free to pass between the two subreflectors. The dimensions of
2 the antenna are such that the reflected signals and the direct
3 pass through signal have a phase difference of 360° which makes
4 them in phase with each other. This permits the signals to be
5 constructively mixed thereby increasing the efficiency of the
6 antenna as compared to a conventional Cassegrain antenna.

7
8 The two antennae 12, 14 are each provided with a line feed
9 for receiving a polarized satellite signal. In the preferred
10 embodiment, slot antenna probes (Figure 3 or 4) are located in the
11 back of each antenna. The signal is coupled from the slot antenna
12 into a microwave PCB or waveguide in the back of each antenna.
13 The antenna probes are attached to a circuit board (Figure 3 or
14 4), where two orthogonal linearly polarized signals are both
15 extracted from a circularly polarized satellite signal. The two
16 linearly polarized signals are fed into a 90° hybrid and two
17 circularly polarized signals are extracted. The signals of the
18 same circular polarization from the same antenna are amplified and
19 combined in the beam forming network 34. The antennae described
20 herein can also be used to receive a linearly polarized satellite
21 signal if the slot orientation is aligned with the polarization of
22 the satellite signal.

Turning now to Figures 3 and 3a, an exemplary beam forming network 34 includes thirty-two elements in eight groups. Typically, the elements are placed less than one wavelength apart from each other in order to achieve the best efficiency. An enlarged view of one group 34a is illustrated in Figure 3a. Each of the eight groups includes a high Z branchline coupler 36 to couple from the slot 32 (Figure 2) to a microstrip 44. A high impedance hybrid 38 is employed to change the linearly polarized signals to circularly polarized signals. A quarter-wavelength impedance transformation is introduced before the hybrid. The impedance transformation allows a precise hybrid to be implemented at higher impedance. Implementing the hybrid at higher impedance can increase the signal loss slightly. However, the performance benefit gained from precise hybrid implementation significantly outweighs the increase in signal loss. After the hybrid, a T-combiner 40 is used to combine signals of the same circular polarization from two adjacent hybrids and feed the signals to amplifiers 42. Figures 3 and 3a show that four signals are combined and fed to each low noise amplifier (LNA) 42. The loss from the hybrid and combiners is approximately .5 dB. To reduce the loss, the LNA's need to be placed closer to the hybrid. If the LNAs are placed before the T combiner, the loss will be reduced, but more LNA's will be needed.

1 Figures 4 and 5 show another embodiment 12', 14' of the
2 offset paraboloid linear antenna with line feed. In this
3 embodiment, the cylindrical dish 26' consists of two shallow
4 curved surfaces 26a', 26b' with two sub-reflectors 28a', 28b' and
5 plastic matching and supporting structure 30' in the center. As
6 with the first embodiment, the use of two subreflectors (instead
7 of one) increases antenna efficiency. According to this
8 embodiment, a rectangular wave guide structure 32' is attached to
9 the backside of the antenna dish. The wave guide contains a step
10 tooth polarizer stud 33' in the middle of the wave guide. The
11 polarizer stud 33' within the rectangular wave guide 32' converts
12 the signal from linear polarization into circular polarization.
13 The use of a waveguide polarizer to convert from linear
14 polarization to circular polarization results in a simpler BFN 34'
15 and much lower front end circuit loss.

17 Various pieces shown in Figures 4 and 5 can be extruded,
18 molded, or stamped and assembled together. Each antenna contains
19 two rows of multiple antenna feeds (probes) 31', 35' (located at
20 one-quarter of a wavelength from the back plate 37') distributed
21 over the entire antenna on the top and bottom plates of the
22 waveguide 32'. The antenna feeds (small pins) 31' on the upper
23 side of the antenna extract a (left or right) circularly polarized
24 signal and the antenna feeds 35' on the lower side of the antenna

1 the antenna extract a (right or left) circularly polarized signal.
2 The multiple antenna feeds on the same side of the antenna are
3 connected to circuit board or wave guide where signals from these
4 probes are amplified and combined in the beam forming network
5 (BFN) 34'.

6
7 In both the antenna assemblies shown in Figures 2 and 4, the
8 antenna physical aperture is divided among two parabolic linear
9 dishes, reducing the overall height by half. Each dish includes
10 multiple feeds instead of a single feed, thereby maintaining the
11 overall antenna efficiency. The antenna shown in Figure 4 uses a
12 polarizer to convert the circularly polarized signals directly
13 from the antenna. This allows the use of a simpler beam forming
14 network (BFN) 34' because no hybrid is used. This design also has
15 lower front end loss and lower cost due to the reduced number of
16 LNAs needed.

17
18 The BFN 34' suitable for use with the antenna assembly shown
19 in Figure 4 is illustrated together with a microstrip filter 39'
20 in Figure 6. The BFN 34' is simpler than the previous embodiment.
21 No hybrid is needed because the signal extracted from the antenna
22 probe is already circularly polarized. The elimination of the
23 hybrid reduces the signal loss, reducing the required number of
24 low noise amplifiers 42' and reducing the production cost. As

1 illustrated in Figure 6, a simple microstrip filter 39' is
2 incorporated with the BFN 34'. This allows adjacent channel
3 signal interference to be filtered out. A hybrid may be used in
4 conjunction with the BFN to receive linearly polarized satellite
5 signals.

6
7 Figure 7 illustrates, in schematic block diagram form, a
8 preferred embodiment of the present invention including all of the
9 circuits and systems involved in providing satellite
10 communications in a moving vehicle. The overall system 100
11 includes components which are mounted above the rotatable platform
12 16 (Figure 1) as well as components mounted on the base plate
13 below the platform. The components mounted above the platform are
14 shown in Figure 7 surrounded by a phantom line box. These
15 components include the two antennae 12, 14, each having a
16 beamforming network (BFN) 34, 34-1. As mentioned above, the
17 outputs of the BFNs are coupled to a phase shifter/combiner 41.
18 More particularly, the output of one of the BFN connects to the
19 input of a phase shifter via a flexible coaxial cable. The output
20 of the phase shifter is connected to one of the input ports of a
21 two-to-one combiner. The output of the other BFN is connected to
22 an attenuator or amplifier (not shown) to adjust the gain and then
23 to the other input port of the combiner. The phase shifter is
24 used to adjust the time delay or phase difference between the

1 signal received by the two dishes. The attenuator or amplifier is
2 used to attenuate or amplify the signal by the same amount as the
3 loss or gain of the phase shifter so that the power of the signals
4 from both BFN's are equal before they are combined. The output of
5 the combiner 41 is passed via the rotary joint 20 to the
6 retransmission tuner 116 located on the base plate below the
7 rotatable platform. Also included above the rotatable platform
8 are an elevation motor 22 and a phase shifter controller 43.

9
10 The connection of DC power and various control signals is
11 effected via the slip ring 20. The preferred embodiment of the
12 slip ring is a number of concentric circular traces on a circuit
13 board surrounding the rotary joint and mounted to the rotatable
14 platform. A corresponding number of brushes are mounted on
15 another circuit board surrounding the rotary joint and mounted on
16 the base plate. The brushes are preferably made from beryllium
17 copper pins with brush blocks on their ends. The brush blocks are
18 made from a phosphor bronze alloy with silver plating. The
19 circuit boards are aligned so that each brush block contacts one
20 of the circular traces.

21
22 The remainder of the components of the system 100 which are
23 located on the exterior of the vehicle include a power
24 supply/charger 102, a battery 104, a solar cell 106 and/or a wind

1 powered generator 108, preferably an AC adaptor 110, tracking
2 circuitry/microprocessor 112, an azimuth motor 114, a
3 retransmitter 116, a retransmission antenna 118, and a receiver
4 120 having an antenna 121. The power supply 102 provides power to
5 all of the components from the battery 104 and/or from a solar
6 cell 106, wind powered generator 108, or AC adaptor 110. It will
7 be appreciated that when power is available from the solar cell
8 106, wind powered generator 108, or AC adaptor 110, it may be used
9 by the power supply 102 to charge the battery. It will also be
10 appreciated that the AC adapter 110 is preferably included so that
11 the battery not be depleted in situations where AC power is
12 available, e.g. on a boat moored in a slip. The azimuth,
13 elevation control and motor driver/antenna tracking control/sensor
14 112 control the azimuth motor 114 (rotating platform) and
15 elevation motors 22 which points the antennas to the desired
16 direction and keeps them locked on to a satellite. These circuits
17 also control the phase shifter control 43 and receive RSSI
18 (received signal strength indicator) input from both the
19 retransmitter 116 (for satellite tracking) and the receiver 120
20 (for channel selection). As mentioned above, the retransmitter
21 116 retransmits signals received by the antennae 12, 14 via a
22 different wavelength antenna 118 to a vehicle inboard unit
23 (described below), and the receiver 120 receives signals via an
24 antenna 121 from the vehicle inboard unit.

1 The vehicle inboard unit components are shown at the lower
2 portion of Figure 7. They generally include a receiver antenna
3 122 coupled to a receiver 124 which is coupled to a demodulator
4 126 which is coupled to a processor 130. The processor 130 is
5 also coupled to a transmitter 128 which is coupled to a
6 transmitting antenna 129. The receiver 124 converts the received
7 signal to a frequency acceptable to the demodulator 126 and the
8 demodulated data is processed in the data processor 130. The
9 output of the data processor is passed to, e.g., a video display
10 and a user interface 131. Commands entered via the user interface
11 are decoded by the data processor 130, e.g. to determine which
12 channel has been selected. This information is passed to the
13 transmitter 128 and transmitted to the receiver 120. Based on
14 that information, the receiver 120 instructs the tuner-
15 retransmitter 116 to switch to a different channel and instructs
16 the antenna and BFN to switch to different polarization. The
17 circuits 112 control the azimuth and elevation motors which points
18 the antennae to the desired direction. The sensor in these
19 circuits senses the vehicle motion which allows the azimuth and
20 elevation control to compensate for the vehicle motion by moving
21 the antenna pointing in the opposite direction of the vehicle
22 motion. In addition to motion compensation operation, the antenna
23 tracking algorithm preferably dithers the antenna pointing
24 direction to refine the antenna tracking. If the elevation

1 pointing is adjusted, the phase shifter 41 needs to be adjusted
2 accordingly to compensate for the difference in the path delay
3 experienced by the signal via two antennae. This is done also
4 under the control of the phase shifter control 43.

5
6 In order to point the antennae at the desired satellite
7 position while the vehicle is moving, the antenna controller 112
8 (preferably embodied in a microprocessor) steers the antennae in
9 both azimuth and elevation angle in response to motion sensors 113
10 to achieve motion compensation. The preferred embodiment uses
11 accelerometers and yaw, roll, and pitch sensors to sense the yaw,
12 pitch, roll rates, longitudinal and lateral acceleration of the
13 vehicle. The estimated yaw, roll and pitch rates are integrated
14 to yield the vehicle yaw, pitch, and roll angle. This is used in
15 a coordination transformation to the earth-fixed coordinate system
16 to determine the azimuth and elevation travel of the antennae.
17 The antennae will be turned in the opposite directions by the same
18 amount to counteract the vehicle motion. Any resulting pointing
19 error is detected by a dithering process and corrected by the
20 antenna tracking system 112. Drift due to the inertia bias is the
21 most significant source of pointing error and the tracking system
22 compensates for it with dithering.

The motion compensation is accomplished through the following azimuth (Az) and elevation (El) update Equations (1) and (2).

$$Az_{k+1} = Az_k - (\phi_x \cos(Az_k) \tan(El_k) + \phi_y \sin(Az_k) \tan(El_k) + \phi_z) \Delta t \quad (1)$$

$$El_{k+1} = El_k - (-\phi_x \sin(Az_k) + \phi_y \cos(Az_k)) \Delta t \quad (2)$$

where

Az_{k+1} is the new azimuth angle estimate relative to the vehicle body coordinate,

Az_k is the most recent azimuth angle derived from the motor encoder output,

El_{k+1} is the new elevation angle estimate relative to the vehicle body coordinate,

El_k is the most recent elevation angle derived from the motor encoder output,

ϕ_x, ϕ_y, ϕ_z are the newest roll, pitch, yaw sensor outputs minus the estimated bias, i.e., $\phi_x = \phi_{x,raw} - \text{roll bias}$, $\phi_y = \phi_{y,raw} - \text{roll bias}$, $\phi_z = \phi_{z,raw} - \text{roll bias}$, and $\phi_{x,raw}, \phi_{y,raw}, \phi_{z,raw}$ are the raw output of the roll, pitch, yaw sensors, and

Δt is the update time interval.

For accurate motion compensation, it is important that the bias for each sensor be properly estimated and compensated. A simple way to estimate the roll and pitch bias according to the invention is to monitor the output of longitudinal and lateral

1 accelerometers as follows. The acceleration on the longitudinal
 2 accelerometer is $y = g \sin(\text{roll angle})$ where g is the gravity
 3 acceleration. If y is not changing, there is no roll angle change
 4 and the readout of the roll angle sensor is the bias in roll
 5 sensor. The acceleration on the lateral accelerometer is $x = g$
 6 $\sin(\text{pitch angle})$ where g is the gravity acceleration. If x is
 7 not changing, there is no pitch angle change and the readout of
 8 the pitch angle sensor is the bias in pitch sensor. When the
 9 antenna has locked on and tracked the satellite signal, the
 10 estimate of the yaw sensor bias can be performed using either of
 11 the following pairs of Equations (3) and (4) or (5) and (6).

$$12 \quad 13 \quad \text{Yaw Sensor Bias} = \Delta Az + \Delta El \tan(Az) \tan(El) \quad (3)$$

14 and

$$15 \quad \text{Pitch sensor bias} = \Delta El \sec(Az) \quad (4)$$

16 assuming that roll bias has been calibrated to zero, or,

$$17 \quad 18 \quad \text{Yaw Sensor Bias} = \Delta Az + \Delta El \cot(Az) \tan(El) \quad (5)$$

19 and

$$20 \quad \text{Pitch sensor bias} = \Delta El \csc(Az) \quad (6)$$

21 assuming that pitch bias has been calibrated to zero,

22
 23 where ΔAz and ΔEl are the antenna correction rates derived from
 24 monitoring the motor encoder output.

1 The bias calculation algorithm described above allows the
2 biases in the roll, pitch, and yaw sensors to be continuously
3 estimated and updated and removed from the measurements.
4

5 A preferred embodiment for the antenna controller 112 obtains
6 an estimate of the pointing angle error by "mechanically
7 dithering" the antenna position. An antenna pointing error
8 estimate is then used to refine the antenna pointing with a close
9 loop tracking operation. According to the antenna tracking
10 algorithm, the antenna is dithered to the left, right, up, and
11 down of the target by a certain amount. The received signal
12 strength indicator (RSSI) is monitored during this dithering
13 action to determine the pointing error of the antennae. The
14 antennae pointing is then adjusted toward the direction of maximum
15 signal strength to refine the antennae tracking.
16

17 According to a preferred embodiment of the invention, the
18 antenna controller 112 obtains an estimate of the pointing angle
19 error by "electronically dithering" the antenna position.
20 Electronic dithering in the elevation direction is achieved by
21 changing (incrementing or decrementing) the phase shift of the
22 phase shifter by a certain amount. This is equivalent to moving
23 the antenna beam (upward or downward) in elevation. Dithering in
24 the azimuth direction is achieved by adding phase shift in the

1 BFN. The signals from the antenna probes are split into two
2 groups within the BFN, each containing signals from half the
3 number of the probes. One group contains signals from one side of
4 the BFN and one group contains signal from the other side of BFN.
5 The signals within each group are amplified and combined into a
6 single signal. One of the combined signals is passed through a
7 phase shifter before combining with another signal. By adjusting
8 (incrementing or decrementing) the phase shift through the phase
9 shifter by a certain amount, the azimuth direction of the antenna
10 beam can be dithered.

11
12 Although the electronic dithering is achieved by adjusting
13 the phase shift of the phase shifter, the electronic dithering is
14 different from the conventional phased-array antenna where the
15 electronic beam can be steered via the use of the phase shifters.
16 The key difference between the electronic dithering operation and
17 the operation of a phased array antenna is that the former only
18 needs to move the antenna beam by a small amount while the latter
19 needs to steer the antenna beam toward all possible scan angles to
20 target a signal source. The design and implementation of the
21 "electronic dithering" antenna and the phased array antenna are
22 therefore quite different. The advantage of the "electronic
23 dithering" is that the power required is reduced as compared to
24 that required for constantly mechanically dithering the antenna

1 assembly. A second advantage is that the "electronic dithering"
2 can be performed at a much faster speed than the "mechanical
3 dithering". Fast dithering operation means the antenna can track
4 faster, which can eliminate the need for motion compensation and
5 all the components (accelerometers and pitch, and yaw sensors)
6 required by the motion compensation, resulting in a significantly
7 lower cost implementation. It should be also noted that the
8 "electronic dithering" operation described above is not limited to
9 the present embodiment of the paraboloid linear antenna. The same
10 principle can be applied to other type of antenna as long as there
11 is a way of adjusting the phase shift to move the antenna beam to
12 a slight offset angle with respect to the target pointing angle of
13 the antenna.

14
15 When the antennae assembly is first powered up, the
16 controller microprocessor 112 which controls the azimuth and
17 elevation motors 114 and 22 commands the two motors to move and
18 monitors the optical encoders to check if the two motors respond
19 to the command. After that, the motion compensation algorithm is
20 turned on. The antennae are moved to scan through possible
21 satellite positions to search for a satellite signal. The typical
22 method is to scan the 360 degree azimuth angle at a given
23 elevation, incrementally change the elevation angle, and repeat
24 the azimuth scan. Preferably, an electronic compass is utilized

1 and the location of the satellite is known. Thus, it will not be
2 necessary to scan the entire hemisphere, but only a relatively
3 small region based on the accuracy of the compass and the
4 satellite position. The antennae dither action is not turned on
5 during the initial satellite location. The antennae controller
6 monitors the RSSI via the power monitor. If the power monitor
7 detects that the signal strength exceeds a certain threshold, the
8 scanning is stopped immediately and the antennae dithering
9 algorithm is turned on to allow the antennae to track the signal.
10 The demodulator 126 and the data processor 128 are monitored to
11 see if the antennae are pointed at the desired satellite and if
12 the signal is properly decoded. If that is the case, the signal
13 lock is achieved. Otherwise, the antenna dithering is disabled
14 and the scanning is resumed.

15
16 If the signal lock is achieved, the antennae tracking
17 algorithm continues to refine the antennae tracking. The
18 processor which controls the motors continues to report the motor
19 position with a time tag. In the preferred embodiment, the motor
20 position is translated into a satellite position (elevation and
21 azimuth) in space. In the case that the signal is blocked by
22 trees, buildings, or other obstacles, the power monitor and the
23 receive data processor can immediately detect the loss of signal.
24 The antenna tracking algorithm will command the motor controller

1 to move the antenna back to point at the last satellite position
2 recorded, when the satellite signal was properly decoded. In
3 addition, upon loss of signal, the antenna dithering tracking
4 algorithm will be temporarily turned off. If the power monitor
5 detects the signal power (exceeding some threshold) again or the
6 data processor detects the signal lock again, the antenna
7 dithering algorithm will be turned on again to continue tracking.
8 After a certain time-out period if no signal strength exceeding
9 the threshold is detected by the power monitor or the data
10 processor does not detect signal lock, the antenna scanning
11 algorithm will be initiated to scan for signal again. The antenna
12 scanning algorithm for signal re-acquisition will scan in a
13 limited region around the last satellite position recorded, when
14 the satellite signal was properly decoded. If the scanning does
15 not find the satellite signal, a full scan of 360 degrees of
16 azimuth angle and all possible elevation angles will be conducted.
17

18 Depending on the elevation angle, the satellite signal will
19 arrive at each antenna at a different time; the lower the
20 elevation angle, the greater the difference in signal arrival time
21 between the two paraboloid linear antennae. The phase shifter 41
22 is used to compensate for the signal phase difference between the
23 received signals from the two paraboloid linear antennae such that
24 the resultant phase of the two received signal is the same

1 resulting in maximum combined power. If the phase shifter is not
2 used to compensate the phase difference, the two resultant signal
3 phases can differ by 180 degrees, the two signals can cancel each
4 other, resulting in minimum power. The amount of phase shift in
5 the phase shifter is determined by the elevation angle and the
6 separation of the two antennas according to Equation (7) below,
7 where D is the distance between the antennae, θ is the elevation
8 angle, and λ is the wavelength of the received signal.

9
10
$$\phi(\text{in radians}) = D \cdot \cos \theta / \lambda \quad (7)$$

11
12 The signal experiences different delays before it arrives at
13 the different antennas. The difference in signal delays depends
14 on the elevation arrival angle of the signal relative to the
15 antenna. The phase shifter is used to compensate for the phase
16 differences between the signals from the two (or more) antennas
17 due to the difference in signal delays. The elevation angle
18 information needed by the phase shifter is provided by the motion
19 compensation and antenna tracking subsystem.

20
21 A typical satellite system has multiple frequency-division
22 channels over the entire band. As an example, the Direct
23 Broadcast Satellite (DBS) frequency band is from 12.2 to 12.7GHz.
24 The signal is transmitted via two antenna polarizations (left-

1 handed circular and right-handed circular polarization). Each
2 antenna polarization carries 16 transponder channels over the
3 entire frequency band (12.2GHz to 12.7GHz). The satellite
4 receiver/set top box receives only one (transponder) channel
5 within the entire band at a time. The phase shift compensation
6 required by each phase shifter will depend on which channel the
7 user is receiving as shown in the Equation (8),
8

$$9 \quad \text{Phase Shift} = w_i * \Delta\tau \quad (8)$$

10
11 where w_i is the frequency of the user channel, and $\Delta\tau$ is the path
12 delay. For the DBS example, the phase shift at the lowest channel
13 (at 12.2GHz) and the highest channel (at 12.7GHz) with a path
14 delay of around 7 inches differs by 106.7 degrees. Thus, it is
15 necessary to know which transponder channel the user is viewing in
16 order to compensate for phase shift properly.
17

18 The user channel information can be retrieved from the
19 satellite receiver/set top box. In the normal operation mode of
20 the satellite receiver/set top box, the user commands the
21 satellite receiver/set top box via an infrared remote controller
22 or front panel keypad. Most satellite receivers/set top boxes
23 have an additional external data interface called the "data port"
24 (or "low speed data port" for DBS specifically) which also allows

1 the user to control the satellite receivers/set top boxes via a
2 personal computer or similar device. According to one aspect of
3 the invention, this data port is used to retrieve the user channel
4 information so that the proper phase shift compensation can be
5 applied to the antennae array.

6
7 The "data port" interface can override the remote controller
8 and front panel keypad as the primary control for the satellite
9 receiver/set top box. In this mode, the satellite receiver/set
10 top box receives the user command from the "data port" but does
11 not execute it. When the user commands the satellite receiver to
12 select a specific channel, this user command information can be
13 retrieved from the "data port". According to the invention, once
14 the user command is retrieved from the "data port", the same
15 command is looped back into the satellite receiver/set top box via
16 the data port to be executed. Since the loop back time delay is
17 very short, the set top box appears to be directly under the user
18 command. The user command retrieved from the "data port" is
19 parsed to decode which transponder channel the user has selected.
20 This user channel information and elevation angle are used to
21 compute the required phase shift to control the phase shifter. A
22 detailed example of the operation flow for DBS set top box "low
23 speed data port" interface is described below with reference to
24 Figures 7a and 7b. Note that in the specific example, each

1 transponder channel contains 4 or 8 video channels in time-
2 division multiplex format.

3
4 Note that the user transponder channel decoded via data port
5 can be passed to tuner1 116 of the re-transmitter and tuner2 124
6 to set the proper tuner frequency for the selected channel.

7
8 By using the "data port" in this manner, the "phased-array"
9 satellite antenna can be operated with any off-the-shelf satellite
10 receiver/set top box having a "data Port".

11
12 The implementation of a precise phase shifter over the entire
13 operating temperature range and the operational life of the
14 product is complicated and typically expensive. Another approach,
15 according to the preferred embodiment, is to use a low cost, less
16 precise phase shifter and, during signal reception, dither the
17 phase shift to determine which phase shift produces the highest
18 signal strength. The function of the phase shift control 43 is to
19 perform such a dithering function and to monitor the output signal
20 strength. It is expected that the optimal phase shift for a
21 certain elevation angle will drift very slowly over time. Thus,
22 the dithering operation of the phase shifter does not need to be
23 repeated very often for a given elevation angle.

1 Referring now to Figure 7a, the hardware of the invention
2 takes control of the settop box at 500, activates the set top box
3 at 502, disables direct user entry at 504 and gets primary status
4 at 506. The hardware of the invention monitors user channel
5 selection at 508. If the user inputs an invalid channel, a
6 default channel is selected at 510. At 512, the channel selection
7 (or the default channel) is transmitted to the phase shifter and
8 tuner for appropriate phase shifting and tuning. So long as
9 external control is maintained as indicated at 514, the invention
10 continues to monitor and parse user commands at 516 (further
11 described below with reference to Figure 7b). If it is determined
12 at 514 that external control is to be turned off, direct user
13 entry is enabled at 518, the set top box is put in standby mode at
14 520 and the external controller is turned off at 522.

15
16 Turning now to Figure 7b, the data port interface user
17 command parsing starts at 550. A user command is obtained at 552.
18 If it is determined at 554 that no key has been pressed, the
19 function exits at 556. If it is determined at 554 that some key
20 was pressed, it is then determined at 558 whether the pressed key
21 is a numeric key. If the key pressed was a numeric key, the
22 keypress is entered at 560 and the user command is sent at 562.
23 If the key pressed was not numeric, it is determined at 564
24 whether the key pressed was an up or down key. If it is not an up

1 or down key, it is determined at 566 whether it is the OK key. If
2 it is the OK key, the video channel selected by the user is
3 entered at 568. If it is determined 564 that the key pressed is
4 the up or down key, the current selected channel is incremented
5 (up key) or decremented (down key) at 570. Once the selected
6 channel is determined it is stored at 572 and compared at 574 to
7 determine whether the selected channel is a valid channel. If the
8 channel is a valid channel, the channel ID is sent to the phase
9 shifter and the tuner at 578. If the channel is invalid, either
10 no action is taken (in the case of an up/down key) or the previous
11 channel is not changed at 576 (in the case of the OK key).

12
13 Referring now to Figure 8, the elevation of the antennae 12
14 and 14 is controlled by rigid arms 24a, 24b which are coupled to a
15 crank shaft 24c. Each of the antennae is pivotally mounted and
16 coupled to a closed track cam 12a, 14a. The ends the rigid arms
17 engage the respective cams such that rotation of the crank shaft
18 causes the antennae to pivot and change the elevation of their
19 look window. In order to track a geostationary satellite from any
20 location in the continental United States, the elevation of the
21 antennae must be adjustable from approximately 15° to
22 approximately 75°. The novel feature of the crank shaft
23 configuration in Figure 8 is that when the antennae 12, 14 look up
24 due to the counterclockwise rotation of crank shaft 24c, the two

1 rigid arms will pull the distance between two antennae closer
2 along the (paraboloid-shaped) rails 12a and 14a. This has the
3 effect of reducing the antenna sidelobe produced by the array
4 factor as explained in more detail below. When the crank shaft
5 rotates clockwise, the antenna look angle is lower and the
6 distance between the two antennae increases. This prevents the
7 antenna closer to the satellite from blocking the signal to the
8 antenna farther from the satellite. Another simpler preferred
9 embodiment is depicted in Figure 9.

10
11 It will be appreciated that when the antennae are rotated
12 away from an elevation of 90° , the antenna 14 will eventually
13 block a portion of the look window of the antenna 12. As the
14 antennae are rotated closer to the 15° elevation, the antenna 14
15 will block the look window of the antenna 12. In order to reduce
16 blockage, the axis of the antenna 14 is located approximately one
17 half inch lower than the axis of the antenna 12. With this
18 arrangement, at an elevation of approximately 20° , the antenna 14
19 blocks the antenna 12 by approximately 12.5% as illustrated in
20 Figure 9. This arrangement also allows the two antennae to be
21 located closer together thereby improving array pattern sidelobe
22 performance.

1 When the separation between the two antennae is larger, the
2 blockage decreases. However, the array pattern sidelobe effects
3 become more severe, when the two antennae are spaced farther apart
4 from each other. In addition, the array pattern sidelobe effects
5 becomes more severe when the antenna is pointing toward a higher
6 elevation angle. Figure 10 illustrate the array pattern sidelobe
7 effects.

8
9 A potential problem due to the array pattern sidelobe is that
10 the antenna may receive the signal from the sidelobe instead of
11 the main lobe. This results in reduced antenna gain, causing the
12 overall received signal-to-noise ratio to degrade. To reduce the
13 array pattern effects at higher elevation, the two antennae need
14 to be moved closer together. However, this will result in more
15 signal blockage at lower elevation when the two antennas are
16 closer. One solution to the array pattern sidelobe and blockage
17 problem is to use the mechanical linkage as depicted in Figure 8.
18 When the crank shaft 24c turns, the cylindrical antennae slide
19 through the rails 12a, 14a, thereby changing their elevation angle
20 and the distances between them. The mechanical linkage allows the
21 two antennae to move closer together when pointing at higher
22 elevation and move farther apart when pointing at lower elevation.
23 When the two antennae move closer, the array pattern sidelobe is

1 reduced, alleviating or eliminating the array pattern sidelobe
2 effects.

3
4 A different solution is to take some signal loss due to
5 blockage at lower elevation, as illustrated in Figure 9, to
6 maintain the array pattern sidelobe. The illustration in Figure 9
7 is based on the two antennae being separated by approximately
8 1.825 times the height of the antennae, e.g. for 4 inch antennae,
9 the separation is 7.3 inches. This represents about 0.6 dB of
10 signal loss and allows the highest antenna side lobe level to be
11 lowered by an additional 4 dB relative to main lobe.

12
13 Another solution is to employ multiple motors to move the two
14 antennae. Two motors are used to adjust the antennae elevation
15 and a third motor is used to move one antenna closer to the other
16 one, when the antennae are pointing at higher elevation angles.

17
18 Each of these three solutions simultaneously address the
19 array pattern antenna side lobe issues and the blockage issues.
20 The second solution allows a good compromise to be achieved.

21
22 As mentioned above, in order to avoid drilling through the
23 vehicle, the signal received by the antennae is re-transmitted at
24 a different frequency to a receiver inside the vehicle. This

1 requires a downconverter and a local frequency source. The
2 satellite signal is typically broadband (such as 500 MHz for DBS),
3 carrying a number of relatively narrow band channels. The
4 allowable bandwidth for re-transmitting the satellite signal into
5 the vehicle is typically narrower, e.g. 100 MHz. The local
6 frequency source is implemented with a tuner to select the desired
7 portion (channel) of the satellite frequency band to be re-
8 transmitted.

9
10 Presently preferred embodiments of a tuner/re-transmitter 116
11 and a receiver 124 are illustrated in Figure 11. The tuner/re-
12 transmitter 116 includes a mixer 202, a voltage controlled
13 oscillator (VCO) 204, a synthesizer 206, an oscillator 208, a loop
14 filter 210, a $\div 2$ divider 212, a $\times 2$ multiplier 214, a bandpass
15 filter (BPF) 216, a combiner 218, a power amplifier 220, and a
16 power meter 222. The retransmitter 116 operates as follows. An
17 incoming signal from the antennae 12, 14 (Figure 1) has a
18 frequency, e.g., in the range of 12.25-12.75 GHz and consists of a
19 number of channels (e.g. 16 channels in each polarization) each
20 having a bandwidth of approximately 30 MHz. The signal is
21 downconverted to approximately 5.725-5.835 GHz (containing four
22 channels) by the mixer 202 and passed through a bandpass filter
23 216 to remove three of the channels. The local oscillator feeding
24 the mixer 202 is derived from a phase-locked loop (PLL) consisting

1 of VCO 204, synthesizer 206, oscillator 208, loop filter 210, $\div 2$,
2 and $\times 2$. Through the action of the phase locked loop, the VCO
3 frequency is coherently related to the oscillator frequency. The
4 output of the VCO is multiplied by two through the $\times 2$ multiplier
5 214 before it is fed into the mixer 202. The use of the $\times 2$ and $\div 2$
6 in the illustrated embodiment allow the VCO to operate at a
7 frequency resulting in the lowest overall phase noise. Alternate
8 embodiments could use a combination of $\times N$ and $\div M$ devices, where N
9 and M are integer values. The phase locked loop also allows the
10 local oscillator frequency to be changed. Different local
11 oscillator frequencies allow different channels to be selected.
12 The overall available bandwidth at 5.725~5.835GHz is 110 MHz.
13 This bandwidth permits multiple channels (e.g. up to three 30 MHz
14 channels) to be transmitted simultaneously. This is done by
15 routing the input 12.25GHz~12.75GHz signal also to another mixer
16 and phase locked loop and bandpass filter (BPF) to select another
17 channel. The bandpass filter for selecting the second channel is
18 offset from the first one by at least 30 MHz. The resulting two
19 25 MHz channels are then combined with the combiner 218 into a
20 single signal. The resultant signal is amplified by the power
21 amplifier 220 and then transmitted out from the antenna 118 to the
22 receiving tuner/receiver 124 inside the vehicle. The power meter
23 222 estimates the strength of the received signal. This is used

1 in the antenna tracking algorithm to keep the antennae pointed in
2 the right direction.

3
4 The receiver 124 is similar in design to the retransmitter
5 116. The receiver includes a low noise amplifier (LNA) 224, a
6 mixer 226, a VCO, a synthesizer 230, a loop filter 232, a x2
7 multiplier 234, a ÷2 divider 236, and an oscillator 238. The
8 operation of the receiver is similar to that described above with
9 respect to the retransmitter. The receiver receives the 5.25-5.35
10 GHz from the retransmitter and downconverts the signal to a lower
11 frequency range (e.g., 950MHz-1.45GHz) which is then processed by
12 the demodulator (126 in Figure 7).

13
14 An alternative embodiment of a re-transmission scheme is to
15 demodulate and decode the satellite signal. The signal
16 transmitted by a satellite typically consists of a number of
17 signals which are frequency division multiplexed (FDM) from 16 to
18 32 transponders in a satellite. A single channel satellite
19 demodulator and decoder selects one transponder signal to process.
20 The data carried by a transponder signal can be further broken
21 down into multiple time division multiplexed (TDM) data streams.
22 The multiplexed digital data streams are processed via a signal
23 de-multiplexer and a router, and some of the data streams are
24 retransmitted with off-the-shelf wireless LAN equipment such as

1 IEEE 802.11a or 802.11b transceivers. The demultiplexer
2 disassembles the desired data streams to be retransmitted and
3 repackages these data streams into the format used by the 802.11
4 or Bluetooth transceivers. The router reassembles the reformatted
5 data streams into the symbol stream to be re-transmitted and
6 attaches the ID of the destination transceiver to the data stream.
7 This method may be preferable if the satellite antenna is used for
8 bidirectional data communications. The satellite communications
9 can also be used as a backhaul network connection of the local
10 area network (LAN) to the WAN (wide area network). It is also
11 desirable in situations where a network of devices need to be
12 coupled to the same satellite antenna.

13
14 As mentioned above, the presently preferred power source
15 includes a wind powered generator. Figures 12 and 13 illustrate a
16 radome according to the invention incorporating a wind powered
17 generator. The radome 300 is designed with a forward facing air
18 intake 302, an air ramp 304 adjacent to the intake, an impeller
19 306 adjacent to the ramp, and an air exhaust 308. The impeller
20 306 is coupled to the shaft of a DC generator 310. When the
21 vehicle is in motion, air enters the intake 302, is guided to the
22 impeller 306 by the ramp 304, passes through the impeller 306 and
23 exits through the exhaust 308. The air causes the impeller to
24 turn the shaft of the generator 310. The impeller is preferably

1 located one or two inches above the surface of the vehicle to
2 avoid the boundary layer where the air flow is retarded. The
3 intake ramp to the impeller accelerates the airflow. The rotor
4 blades slow down the airflow. The air exits from the exhaust at
5 approximately the same speed as the air flowing adjacent to the
6 exhaust to avoid air turbulence. Different ways to implement the
7 rotor are possible. The power P obtained from the generator is
8 described by Equation 9 where C_p is the conversion efficiency
9 coefficient, ρ is air density, V is wind speed, and Ra is area of
10 the impeller blades.

$$P = C_p \times \rho / 2 \times V^3 \times Ra \quad (9)$$

11
12
13
14 The output of the DC generator is routed to charge a battery and a
15 DC-to-DC converter which regulates the output power to 12V, 5V,
16 and 3.3V as required.

17
18 The output of the generator is used to charge a rechargeable
19 user replaceable battery pack contained within the radome, and the
20 battery pack is used to power the antennae assembly.
21 Alternatively, a coil and capacitor arrangement such as disclosed
22 in U.S. Patent Number 5,917,310 may be used in lieu of a
23 rechargeable battery. As mentioned above, a photovoltaic panel
24 array may also be used in addition to or in place of the wind

1 generator to ensure that the battery maintains an adequate charge.
2 Also as mentioned above, an AC power adapter is optionally
3 provided in situations where the vehicle will remain stationary
4 within range of an AC power source, e.g. on a boat moored in a
5 slip, or an RV parked in an RV park.
6

7 Another embodiment to provide power to the antennae assembly
8 is to employ a switch circuit which converts a DC power supply
9 inside the vehicle (for example, from the 12 V cigarette lighter)
10 to an AC signal at, e.g. 100 kHz. The switching AC signal is
11 passed through the vehicle window through an inductively coupled
12 or capacitively coupled device. The inductively coupled or
13 capacitively coupled device is attached to the opposite sides of
14 the window at the same position. The inductively coupled or
15 capacitively coupled device allows the electrical energy to be
16 coupled through the window and passed to the antenna assembly on
17 top of the vehicle.
18

19 Figures 14-16 illustrate preferred aspects of the radome
20 according to the invention. As shown in Figure 14, mounting
21 brackets 312, 314 located on opposite sides of the radome 300 are
22 adapted to clamp to the vehicle roof rack rail assembly or grip a
23 suitable feature depending on the available mounting points. The

1 clamps employ security locks 316, 318 to protect the unit from
2 unauthorized removal.

3
4 Figures 15 and 16 illustrate how the radome 300 is extended
5 to an open position when the antennae are being used and collapsed
6 to a closed position when the unit is powered down. In
7 particular, when the unit is powered down, the antennae 12, 14 are
8 moved to a 90° elevation angle as shown in Figure 16 thereby
9 decreasing the height of the assembly so that the radome can be
10 retracted. The movement of the radome may be accomplished by
11 either an electric motor 320 as shown in Figure 15 or one or more
12 hydraulic pumps 322, 324 as shown in Figure 16.

13
14 There have been described and illustrated herein several
15 embodiments of a low profile satellite antenna system for mounting
16 on a vehicle. While particular embodiments of the invention have
17 been described, it is not intended that the invention be limited
18 thereto, as it is intended that the invention be as broad in scope
19 as the art will allow and that the specification be read likewise.
20 It will therefore be appreciated by those skilled in the art that
21 yet other modifications could be made to the provided invention
22 without deviating from its spirit and scope as so claimed.